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As the DoD undergoes a reshaping and resizing to achieve a more affordable defense capability, it is also important that weapon systems be developed and manufactured in an environmentally conscious manner. To achieve this goal requires that a change occur in the paradigm that is used to view the weapon system life cycle. The Design Tool for Assessing Manufacturing and Environmental Impact (DTAME) is discussed along with emphasis on the SimBuilder Module. This module was designed such that a novice simulation user could input the relevant data in a user-friendly manner and the simulation model is automatically generated.

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Technical Report 5-20638
Contract No. DAAH01-98-D-R001
Delivery Order No. 050

**Design Tool for Assessing the Manufacturing Environment (DTAME)**
(5-20638)

Final Technical Report for Period
30 August 1999 through 30 September 2000

February 2002

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Redstone Arsenal, AL 35898
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## PREFACE

This technical report was prepared by the faculty of the Industrial and Systems Engineering and Engineering Management Department at the University of Alabama in Huntsville. The purpose of this report is to provide documentation of the work performed and results obtained under Delivery Order 104 of AMCOM Contract No. DAAH01-98-D-R001. Dr. Sherri Messimer was the principal investigator. Dr. Daniel Rocowiak served as co-principal investigators for the project. Mr Daniel Holder and Mr. Raymond Harrell, Engineering Directorate, Missile Research, Development and Engineering Center, provided technical guidance.

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision unless so designated by other official documentation.

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Prepared for: Commander
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Redstone Arsenal, AL 35898

I have reviewed this report, dated February 2002, and the report contains no classified information.

Sherri J Messimer

Principal Investigator

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## 1.0 Introduction

As the DoD undergoes a reshaping and resizing to achieve a more affordable defense capability, it is also important that weapon systems be developed and manufactured in an environmentally conscious manner. To achieve this goal requires that a change occur in the paradigm that is used to view the weapon system life cycle. In today's paradigm, the addressing of environmental concerns occur as a defacto activity after the product, process, and manufacturing plan have been established. Many studies have shown that this reactive approach is not effective. Currently, the DoD and its contractors are in the process of "cleaning up" their facilities and weapon system designs due to inadequate environmental planning.

Proposed actions to effect a more environmentally conscious approach must be enacted early in the life cycle phase to achieve optimal facility and weapon system designs. This paradigm change requires that we view environmental concerns as an important factor in the trade-off decision making that must occur during the early development phases. Assessing pollution impacts and energy consumption during the early phases of product development will result in long term savings and significant reduction pollution (i.e. hazardous waste generation). The impacts of environmental laws and regulations must be assessed during the earliest design phases of product development in order to affect changes in the product, process, or manufacturing plan.

Assessing pollution impacts and energy consumption during the early phases of product development results in long term savings and a reduction in pollution. Tools are needed which allow designers to understand the consequences of their decisions regarding manufacturing options. We believe that to attack this problem we will need to intelligently access and integrate information and regulations from diverse sources in a way that is both timely and meaningful to the end user. Identifying the environmental impact during the early planning stages allows the manufacturer to reduce the impact early when changes in the production system are easily made.

Currently, Program Management Office personnel do not have the expertise to address the environmental impacts of design decisions made during the design process. The Design Tool for Assessing Manufacturing Environmental Impact (DTAME) allows the design engineers, concurrent engineering teams, and Program Managers to understand the environmental consequences of their decisions regarding manufacturing process options early enough in the program life-cycle to affect positive actions.

## 2.0 Objective

The objective of this task is to complete the development of an architecture that will integrate state-of-the-art computer software system applications which uses artificial intelligence techniques to evaluate the feasibility of utilizing composite technology for a proposed weapon system component. This system will build on capabilities and systems developed in two previous research projects: a system used to critique the applicability of a particular composite manufacturing process and an interactive simulator developed to rapidly define, model, and evaluate electronic manufacturing systems. We also utilize results from the Army's fuzzy logic controller for helicopter flight control as part of a search strategy involving genetic algorithms to optimize system configuration.

**3.0 Statement of Work**

The statement of work, as outlined in delivery order 0050 is as follows:

3.1 UAH will perform knowledge acquisition to determine the Formulate, Execute and Critique functions of the system. This will include surveys to gain information, examination of public materials including laws, regulations, scientific research, and engineering findings.

3.2 UAH shall complete the design and prototype of the execute module and complete the implementation, integration and test of the formulation, execute and critique modules. Additionally, the contractor shall support the CAV and Crusader requirements as necessary. This is to include research necessary and sufficient to complete production simulation modeling.

3.3 Software construction shall proceed through the normal phases of requirements definition, design, implementation, testing, and delivery. Special attention shall be given to the modularity, extensibility, and robustness of the system. The contractor shall also allow for various platforms and means of access.

3.4 Periodic review and assessments shall be scheduled at key points in this plan and be a cooperative effort between the government and the contractor.

**4.0 Conclusions**

The following describe how the task objective was met in order of the items within the statement of work.

4.1 Composites and Environmental Issues

In order to effectively design a model, which takes into account, environmental criteria and its important to understand how environmental issues affect the composite industry. Therefore, Table 2.1 lists and describes the five major pieces of legislation which affect all manufacturers.

| |
|---|
| **Name**<br>The Resource Conservation and Recovery<br>Act (RCRA)<br>**Description**: Defines both solid and hazardous wastes and regulates the treatment and disposal of each.<br>**Name**<br>The Toxic Substances Control Act of 1976 (TSCA)<br>**Description**: Regulates chemicals to be imported, created, or used in any manufacturing process. Waste management is included. |

| |
|---|
| **Name** The Emergency Planning and Community Right-to-know Act (EPCRA)<br>**Description**: Requires annual reports of environmental releases of about 300 chemicals and information on efforts to reduce waste, recycle, and recover energy.<br>**Name** Clean Air Act<br>**Description:** Mandates the EPA to regulate air emissions, including listed air toxins.<br>**Name** Clean Water Act<br>**Description:** Mandates the EPA to establish and revises tandards for industrial discharges to surface waters and public treatment facilities. |

**Table 4.1 Environmental Legislation [Fisher and Whittler, 1992]**

The Resource Conservation and Recovery Act (RCRA)

Defines both solid and hazardous wastes and regulates the treatment and disposal of each. The Toxic Substances Control Act of 1976 (TSCA) Regulates chemicals to be imported, created, or used in any manufacturing process. Waste management is included. The Emergency Planning and Community Right-to- know Act (EPCRA) Requires annual reports of environmental releases of about 300 chemicals and information on efforts to reduce waste, recycle, and recover energy. Clean Air Act Mandates the EPA to regulate air emissions, including listed air toxins. Clean Water Act Mandates the EPA to establish and revise standards for industrial discharges to surface waters and public treatment facilities.

How does this legislation specifically affect the composite industry? Fortunately, very few substances used in advanced composites are currently considered hazardous. However, hazardous wastes generated at composite manufacturing facilities generally include solvents and prepregs or resins containing solvents. In addition, personal protective equipment, liners, and bagging materials used in the curing process may also require hazardous waste disposal.

In compliance with the Clean Air Act, companies are required to register air-emission sources such as ovens and autoclaves and obtain prior approval for all new emission sources. Other possible sources of air emissions include mold-release agents, cleaning agents, and other volatile solvents. Many companies also have to place emission controls on their finishing and prepregging operations.

Solid waste is another area for concern in composite manufacturing. Composite materials including prepreg waste is one of the solid waste disposal problems. There are many complex definitions and requirements when dealing with solid waste. Most often any uncured resin is allowed to cure and is labeled as non-hazardous waste. Companies prefer this approach since hazardous waste is about 10 times as expensive to dispose of as nonhazardous waste. In some instances, however, companies, which cure prepreg as a method of treating hazardous waste, may have to hold a permit as a treatment, storage, and disposal facility. Since obtaining a permit is a very costly procedure, many smaller companies may be forced into hazardous waste disposal.

Even though many wastes in the composite industry are not considered hazardous at this time, larger companies may still treat them as hazardous because of their uncertain long term outlook. Materials, currently not on the RCRA list of hazardous materials, may eventually gain that status and there are no "grandfather" clauses in hazardous waste legislation. Ten to twenty years in the future companies do not want expensive clean-up costs putting them out of business. Also, the Occupational Safety & Health Administrations (OSHA) Hazard Communication Standard requires a Material Safety Data Sheet (MSDS), which outlines the important safety and environmental information associated with a product, for all materials deemed hazardous to workers.

Environmental regulations are important to consider when addressing environmental criteria; however, overall waste minimization is important as well. It is estimated that for aerospace applications the industry purchases two pounds of raw materials for every pound in the final composite product. One study authorized by the Center of Excellence for Composites Manufacturing Technology estimated that 2.5 million pounds of prepreg waste are disposed of annually which is equivalent to $1 billion in prepreg and prepreg by-products. Another $25 million is spent on waste disposal [Fisher and Witzler, 1992]. The Guide to Pollution Prevention for the Fiberglass-reinforced and Composite Plastic Industry lists the most common types of waste, origin, and composition as shown in Table 2.2. In the guide there are also a number of waste minimization methods that are given for particular waste streams as summarized in Table 2.3.

| Waste Description | Process Origin | Composition |
|---|---|---|
| Waste solvent | Hands, tool mold, and equipment cleaning | Resin-contaminated solvent |
| Empty resin and solvent containers | Unloading of materials into mixing tanks | Small amounts of residual resin and solvent |
| Laboratory analysis wastes | Formulating and testing | Spent resins, solvents, and finished and semi-finished trial products |
| Cleanup rags | Equipment cleaning operations | Solvents and small amount of resins |
| Pre-preg (previously resin-impregnated) waste fabric | Leftovers from a particular batch or scrapped when product sample does not meet customer specification | Resins and fiberglass substrate (including minor quantities of chemical additives) |
| Empty plastic, paper and cardboard containers with residual peroxides, glass routing and chemical additives | Unloading of raw materials into process tanks | Chemical additives such as Cab-O-Sil" and aluminum trihydrate |
| Expired raw materials | Raw material that has | Usually semi-solid and |

| | | |
|---|---|---|
| | exceeded shelf life or otherwise became unusable | self-cured resin |
| Gelcoat and resin overspray | Overspray during fabrication process | Resins, pigments, catalysts and chemical additives |
| Partially-cured waste resins | Discontinued batch | Contaminated and unusable resin solvents |
| | Volatilized solvent and mold release agents, during curing and open vessels containing solvents | Solvents and volatile monomers |
| Waste water | Equipment cleaning with emulsifiers | Water with organic chemical contaminants and emulsifier |
| Scrap solvated resin | Residue from piping and treated pan at the end of a run | Resins and resin-contaminated solvents |

**Table 4.2 Fiberglass-Reinforced and Composite Plastics Fabrication Waste [EPA,1991]**

| Waste Stream | Waste Minimization Methods |
|---|---|
| Equipment cleaning wastes | Restrict solvent issue. Maximize production runs. Store and reuse cleaning wastes. Use less toxic and volatile solvent substitutes. On-site recovery. Off-site recovery. Reduce rinse solvent usage. Waste segregation. |
| Scrap solvated and partially cured resins | Modify resin pan geometry. Reduce transfer pipe size. Waste exchange |
| Gelcoat resin and solvent oversprays | Change spray design. |
| Rejected and/or excess raw material | Improve inventory control. Purchase materials in smaller containers. Return unused materials to suppliers. |
| Resin and solvent contaminated floor sweepings | Use recyclable floor sweeping compound. Reduce solvent and resin spillage and oversprays by employing alternate material application and fabrication techniques. |
| Empty bags and drums | Cardboard recovery. Container recycling. returnable containers. Use plastic liners in drums |
| Air emissions | Improve/modify material application. Cover solvent containers. Use emulsions or less volatile solvents. |
| Miscellaneous waste stream | Product/process substitution. |

| | |
|---|---|
| Cleanup rags | Efficient utilization of clean programs. Auto-cleaning process equipment. |
| Laboratory and research wastes | Reduce quantities of raw material and products for testing and analysis. |

**Table 4.3 Waste Minimization Methods for Fiberglass Reinforced and Composite Plastics Fabricators [EPA, 1991]**

With the increasing concern about environmental impacts and the upcoming implementation of ISO-14000 environmental systems standards, companies will be looking for more cost-effective methods to include environmental criteria into the design process. A simulation model which uses inventory analysis to track materials entering and leaving the manufacturing process could greatly enhance a design engineers ability to assess environmental performance before selecting and installing a manufacturing process. The composite industry, because of its many different manufacturing alternatives and its strong need for concurrent engineering, is a good choice to show the viability of this methodology.

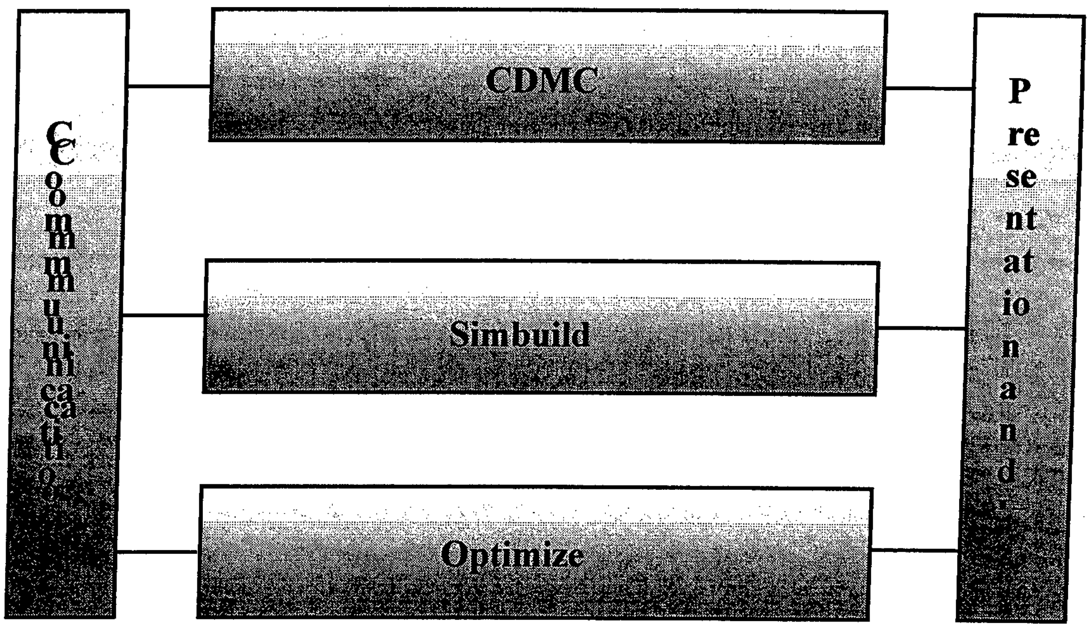
**Developed deeper understanding of CAV manufacturing process including:**

- Researching general VARTM and RTM technology as it is used in the Composite Armored Vehicle process.
- Continued communications with UDLP personnel regarding the CAV project and received feedback on design and manufacturing tools that was incorporated into the new system software.
- Utilized the AFT, Sponson Sidewall, and Skirt spreadsheets from UDLP as a basis for the simulation.

There is no single expert for all of the aspects of composite design and manufacture. This distinguishes the type of system that is required for a solution to the problem from the typical expert system. Further there is a need to establish the sources of the expertise. These sources are both geographically and organizationally distributed. Some experts will belong to different organizations located at different places. For example, the experts in the design and use of composite materials maybe government personnel attached to the CAV project while the experts in composite materials manufacturing simulation are government personnel attached to AMCOM and the engineering experts are professors at the University of Alabama in Huntsville and the University of Tulsa. This distribution of expertise makes the knowledge acquisition and knowledge engineering problem difficult. Additionally, it indicates the need for a system of communication. In our research thus far we have concentrated on building a common medium for the modular acquisition and engineering of knowledge and have made some tentative efforts toward attacking the communication system needed to bridge the geographical and organizational distribution of expertise and information sources.

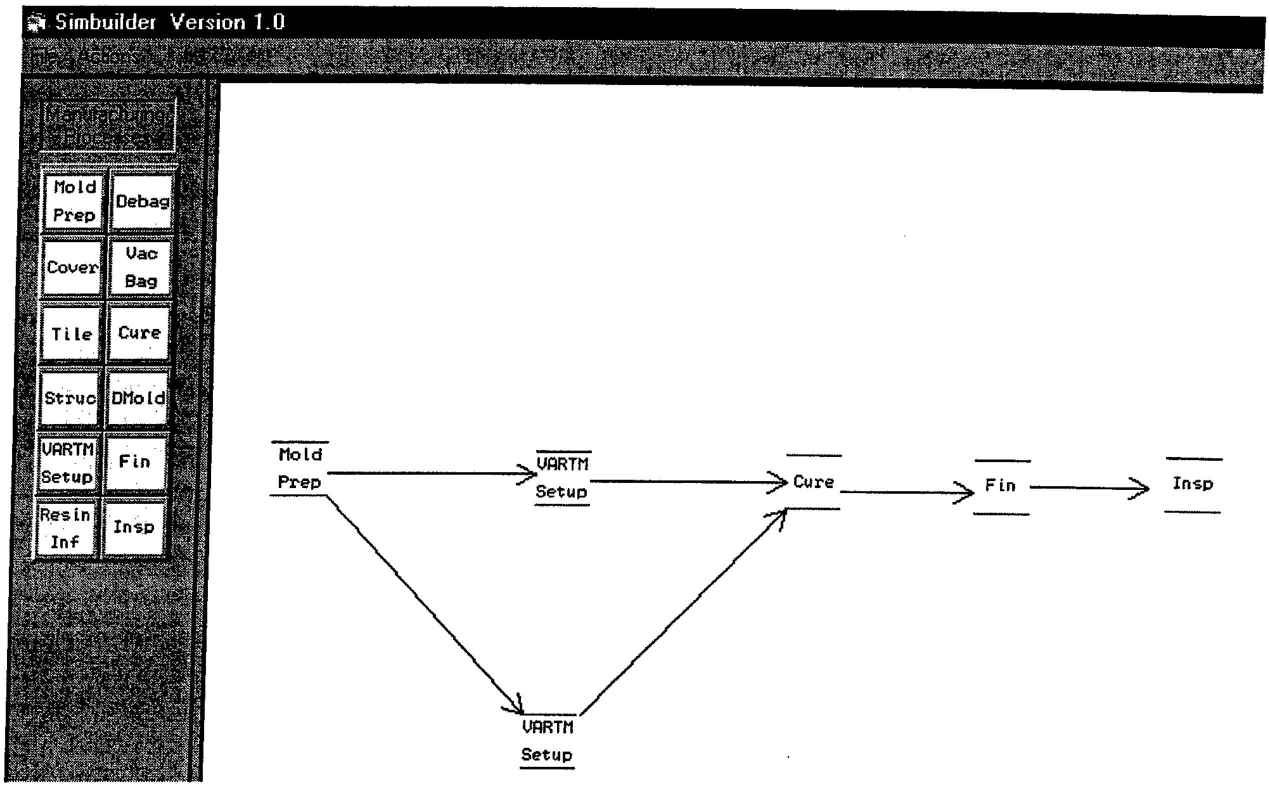
4.2 (covers 3.2 and 3.3)
The modules of DTAME have been prototyped in parallel. The result is a mix of platforms and languages. However, there is a systematic approach to the construction. The flow of the operations would begin with CDMCS, continue to the static analyzer, be exercised in the simulation environment, and finally be submitted to for optimization. This set of operations will be supported by the system wide utilities that attempt to unify the interprogramatic interface and the user interface, and provide for communication among team members. Diagram 4.1 illustrates the general structure and flow.

## Figure 4.1 DTAME Conceptual Architecture



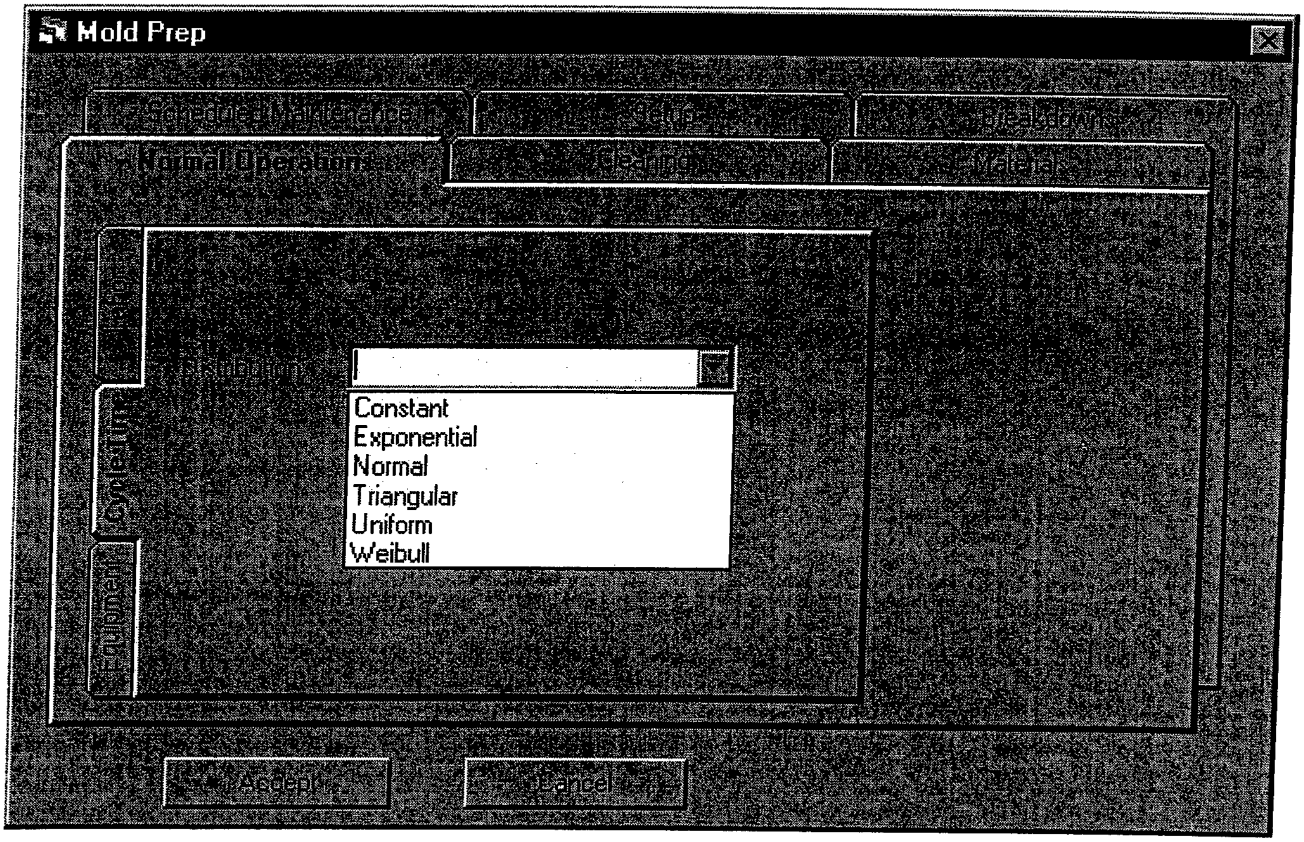

The major addition to the system is the SimBuilder module. It was developed by UAH to provide a mechanism for generating simulations from initial specifications. Simulated a manufacturing system provides insight into bottlenecks and other manufacturing issues. The simulation provides user with ability to understand the impact of system variability on performance parameters. Witness Simulation models can easily be constructed using this module, thereby enabling novice programmers the ability to build and analyze manufacturing lines quickly. Figure 4.2 shows a line layout that was developed using a "drag and drop " interface to configure process flow data; the user may enter the initial data in a variety of ways. Default input data is provided to the simulation via spread sheet information gathered from various sources including UDLP. The user does not have to enter all the data; they may choose to use the default data instead.

Figure 4.2 Interactive Line Layout



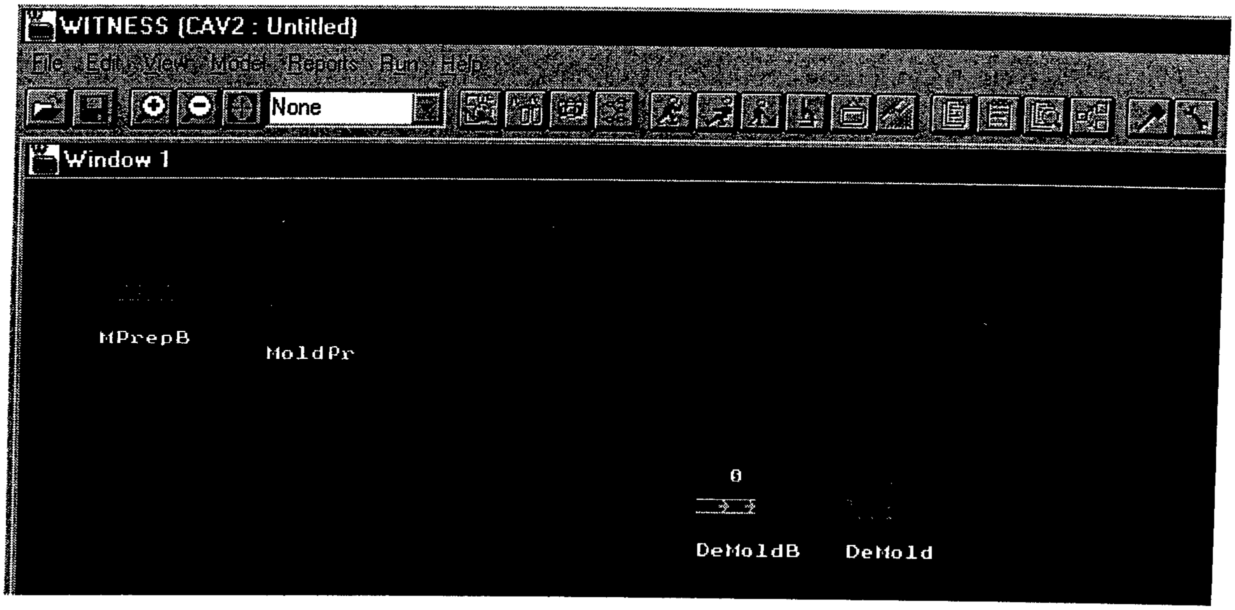

Simulation parameter definition is straightforward and allows the user to save, load, and modify cases. Icons are added to the layout by selecting them with the mouse. Use the left mouse button to move icons and use the right mouse button to edit icon properties and link icons to each other. Lay-up icons represent grouped processes. SimBuilder uses tabbed dialog boxes to define the operating parameters for each process. Open these dialog boxes by selecting an icon with the right mouse button and clicking on "Edit." Figure 4.3 below illustrates the type of interface found in SimBuilder: this input screen for Mold Prep allows data to be entered in an intuitive manner and covers all aspects required to run the simulation. For instance, the Normal Operation tab has been selected in the figure below. Here the user would enter information about cycle time, labor (types) and equipment.

**Figure 4.3 Parameter Definition**



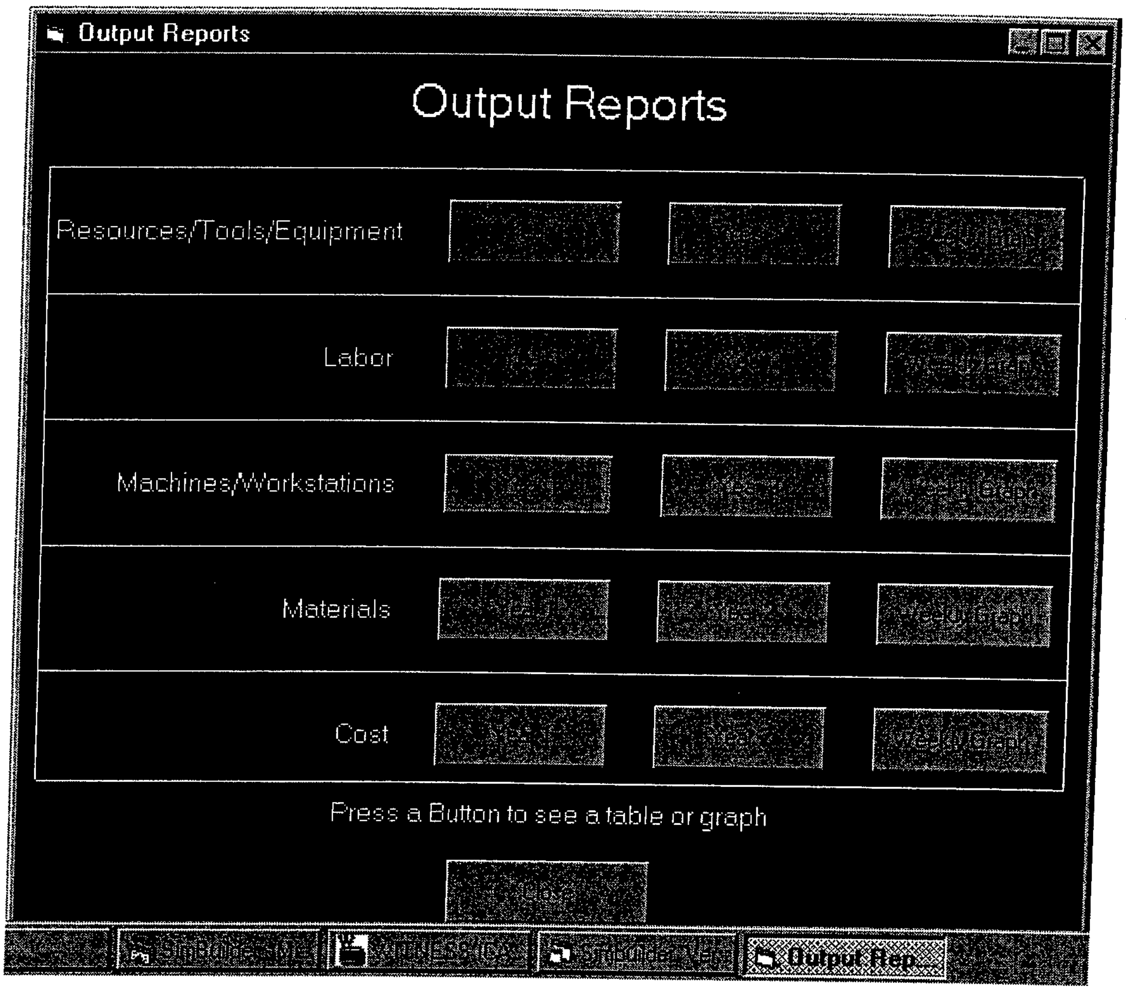

The system produces graphical and tabular data reports on the basis of the user-entered data. A customized designed interface is linked to an Excel spreadsheet. A Witness model is then generated automatically. See Figure 4.4 below.

# Figure 4.4 Witness Model




From the simulation output reports can be generated. Figure 4.5 illustrates the general structure of the output reports. Resources, labor, machines, materials and cost can be tracked. Figure 4.6 shows a sample environment report.

**Figure 4.5 Output Reports**



| Environmental Report | Wt/Finished part | Wt/Week | Cost/Finished part | |
|---|---|---|---|---|
| Waste Type | Avg | Avg | Avg | |
| Discarded RM's | 0.98 | 18.04 | $0.50 | |
| Total Amount of Mat'l in Scrap | 5.99 | 164.31 | $5.56 | |
| Machine Waste | 0.00 | 0.00 | $0.00 | |
| Cuttings | 0.00 | 0.00 | $0.00 | |
| Waste Resin | 0.72 | 19.74 | $0.72 | |
| Solvent Bottoms | 1.92 | 52.60 | $1.92 | |
| Air | 2.40 | 65.71 | $2.40 | |
| Discarded Mat'ls used for good parts or | 2.58 | 70.62 | $2.03 | |
| Mandrel Mat'ls | 1.00 | 27.52 | $1.00 | |
| Bag Mat'ls | 0.42 | 11.54 | $0.01 | |
| Mold Release | 1.00 | 27.52 | $1.00 | |
| Mandrels | 0.15 | 4.04 | $0.00 | |
| Total | 14.58 | 391.02 | $13.12 | |
| | | | | |
| **Environmental Categories** | **Waste/Finished Part** | **Waste/Week** | **Usage/Finished Part** | **Usage/Week** |
| Ext Haz Sub-Rep Quantity | 0.00 | 0.00 | 0.00 | 0.00 |
| Ext Haz Sub-TPQ | 0.00 | 0.00 | 0.00 | 0.00 |
| Toxic Chemical | 0.00 | 0.00 | 0.00 | 0.00 |
| TRI Chemical | 0.00 | 0.00 | 0.00 | 0.00 |
| SARA H-1 | 0.34 | 9.23 | 11.15 | 305.68 |
| SARA H-2 | 0.00 | 0.00 | 0.00 | 0.00 |
| SARA P-3 | 0.00 | 0.00 | 0.00 | 0.00 |
| SARA P-4 | 0.00 | 0.00 | 0.00 | 0.00 |
| SARA P-5 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | |
| Hazardous | | | | |
| Non-hazardous | | | | |

**Figure 4.6 Environmental Output Report**

## 5.0 Recommendations

Interfaces to operational components will need to be developed. These operational components will include access to historical data and real time access to data from the factory floor. The communication support effort will connect the various components of the system. Historical data, simulation models, and real-time data will allow the system to what if' analysis and be able to reprogram operational machines. See Figure 5.1 for an illustration of the future system architecture.

**Figure 5.1 Future Development**